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Testing of components for solar thermal collectors in respect of saline atmospheres

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Abstract

Typical components for solar thermal collectors like glazing materials, absorbers and reflectors are exposed to accelerated weathering tests to analyze their stability and behavior under different climatic conditions including a saline atmosphere. The samples are characterized before, during and after the tests with different methods, including FT-IR spectroscopy and microscopic technologies like AFM microscopy to measure the degradation on different scales and identify the processes taking place. In this article we focus on the solar reflector.

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Keywords: Components for collectors, saline atmosphere, accelerated ageing, characterization

1. Project and objectives

Depending on their location and prevalent climatic conditions, the components of solar thermal collectors have to bear high climatic and mechanical stresses. Besides high temperatures, UV-light, wind, snow, humidity or saline and corrosive atmospheres can be causes for a rapid degradation of materials and components.

Despite these well-known obstacles for solar thermal installations in extreme climates, the aging processes with regard to different climatic and operational conditions are only poorly analyzed. To qualify and enhance the

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durability of solar thermal systems and improve the market opportunities on a world-wide scale, the development of suitable accelerated aging tests is necessary. The German project *Speed*Coll is dedicated to these issues [1].

The aging effects occurring in solar collectors with glass covers are determined primarily by the temperature level in the collector. This temperature level has significantly increased during the last years due to the enhancement of the collector efficiency and the trend towards systems with higher solar fractions with the resulting increase in stagnation times and temperatures. Furthermore, aging analyses of new products on the market such as spectrally selective absorber layers and anti-reflection layers, for example, are needed since only little is known about their long-term behavior.

Next to the influence of increased temperatures, other causes for aging have to be analyzed, especially UV-radiation, moisture and the influence of saline atmospheres. Furthermore the frequent use of solar thermal collectors in Mediterranean countries for the preparation of domestic hot water and solar cooling, a quality check regarding the impact of the saline atmosphere predominating close to the sea-shore in these countries is necessary. This work will complement the activities in modeling of the atmospheric corrosion [2].

Components and materials of solar thermal collectors are tested. The samples are provided by the industrial project partners and tested in the scientific institutes that participate in the project.

In this report, we focus on the component solar reflector. Seven differently coated aluminium-sheets provided from project partners are investigated.

2. Weathering tests

2.1. Outdoor

The samples are exposed to outdoor weathering at six test sites with different climatic conditions under continuous monitoring of the climatic conditions (temperature, humidity, wind, precipitation, UV) and the collector micro climate (temperature and humidity inside the collector). In order to gain worst-case-data some of the test sites are positioned in extreme climates with very harsh conditions (Table 1).

Table 1: Exposition of collectors and components (glazing, absorbers, reflectors) at locations with extreme climates

Climates	Location
Tropical	Kochi, India
Alpine	Schneefernerhaus, Zugspitze, Germany
Aride	Sede Boker, Negev Dessert, Israel
Maritime	Pozo Izquierdo, Gran Canaria, Spain
Moderate	Stuttgart and Freiburg, Germany

2.2. Indoor

Accelerated ageing tests with a variation of the relevant parameters saline atmosphere, temperature, humidity and irradiation are performed in climatic cabinets for samples. Especially hot, humid and salty conditions will be used for the qualification of the materials since they are seen as most demanding and also as most relevant for the application of solar thermal systems in sunny regions with high population which are often located close to the shore line.

3. Characterization methods

The relevant physical properties of the material samples were measured before exposure to weathering. The absorber temperature of all collectors and some selected temperatures at other collector parts (glazing, frame, insulation, e.g.) are measured continuously during exposure in order to set up a data base for the development of suitable accelerated life tests and to detect degradation of the collectors in-situ.

Different non-destructive analytical methods are used for the characterization of the material samples. On the one hand, there are optical methods like FT-IR spectroscopy in transmission (glazing) or reflection mode (absorbers and reflectors) or Raman spectroscopy and Raman microscopy for analyzing the chemical composition and identifying changes due to degradation. In addition, Atomic-Force-Microscopy (AFM) and Auger electron spectroscopy (AES) is used for the investigation of the changes of the surfaces. In this article we focus on the component solar reflector.

3.1. FT-IR

The spectral measurements were carried out with a Fourier transform spectrometer Bruker Vertrex70 equipped with two integrating spheres (a PTFE coated sphere for the shorter wavelength-range ($\lambda < 2{,}0$ µm) and a diffuse-gold coated sphere for the IR ($\lambda > 1{,}7$ µm)) in order to measure both the directly reflected and the scattered radiation. The diffuse part of the reflectance was calibrated with a PTFE standard from National Institute of Standards and Technology (NIST) for the solar range and from National Physical Laboratory (NPL) for the thermal range. The specular part in the solar and the infrared ranges was calibrated with an aluminum mirror from NPL. The accuracy of the reflectance data was better than 1 % in the solar range and better than 2 % in the IR. The solar absorptance/reflectance was calculated by weighted integration of the spectral reflectance with the solar spectrum AM 1.5 according to ASTM E 891. The thermal emittance was calculated by weighted integration of the spectral reflectance with the Planck Black Body radiation distribution at a temperature of 373 K.

3.2. AFM

The AFM unit of the WITec alpha 500 was employed using tapping mode AFM probes (nanosensors with a force constant of 48 N/m and a resonance frequency of about 170 kHz). The cantilever’s dimensions were 225 µm x 38 µm x 7 µm (length x width x thickness). Measurements were taken in air at room temperature, with a resolution of 256 points per line and 256 lines per image and with a scan frequency of 1,5 s/line. A scanning area of 30 x 30 µm² was chosen. Since AFM is very sensitive to surface inhomogeneities, e.g. from fabrication, a variety of measurements was performed. The surface of each sample was analyzed at different positions within the scanning range (100 x 100 µm²) and at each of these, at least three different AFM micrographs were taken. This way, a multitude of images was obtained and analyzed using two surface indicators: surface roughness (SA) and surface area, where the surface roughness is defined by $SA = 1/N \sum|z_i\text{-}z|$ at which N is the number of pixels, z the average height value and z_i the height value at position i.

4. Results

4.1. Outdoor

The chloride deposition was measured by the wet candle method in Pozo Izquierdo, Gran Canaria, Spain over a period of 30 month, beginning in November 2009 [3]. Figure 1 shows the chloride deposition rate for four different measuring points at the test site and the classification in salinity levels according to the ISO 9225 standard.

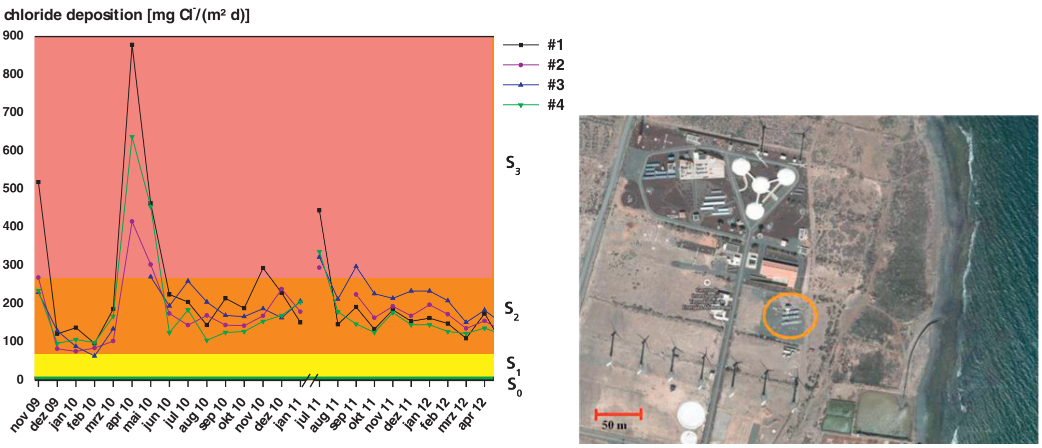


Figure. 1: Chloride deposition measured by the wet candle method in Pozo Izquierdo (left) and location of the outdoor test site in Gran Canaria, Spain (source: google map) (right).

The annual average chloride deposition rate S_d is 205 [mg/(m^2 d)]. According to the ISO 9225 standard, the site has the salinity level S_2.

4.2. Indoor

Accelerated indoor tests in saline atmosphere were performed in a climate cabinet equipped with a salt spray unit. The spray had a concentration of 3% NaCl. One day cycle consists of 2h spraying and 22h hold at 40°C, 93% RH. An acceleration factor of 8x to the chloride deposition rate in Pozo Izquierdo was determined by gravimetric measurements with reflector samples. A picture of the weathered sample after an 18 days cycle in saline atmosphere is shown in figure 2.

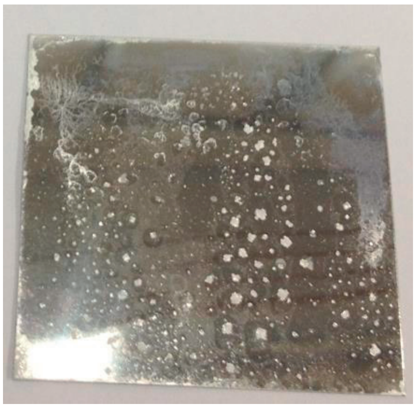


Figure 2: Solar reflector, 5 cm x 5 cm after 18 days cycle in saline atmosphere / correlating 21 weeks in Pozo Izquierdo.

4.2.1. FT-IR

The weathered samples were cleaned before measuring. After a period of 28 days in a defined saline atmosphere cycle, the optical performance of the reflectors has not changed significantly.

In figure 3, the direct solar reflectance for seven different reflectors over the test period up to 28d is shown. The measured diffuse reflectance is drawn in figure 4.

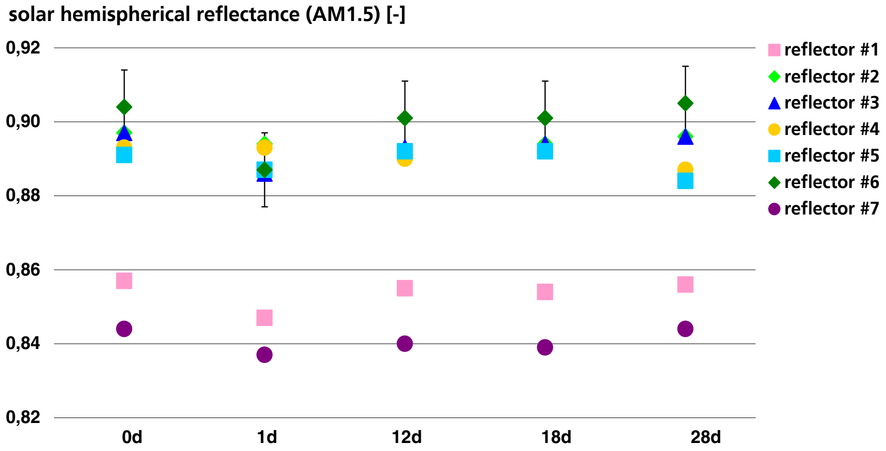


Figure 3: Direct solar reflectance for different saline atmosphere cycles for 7 different reflectors.

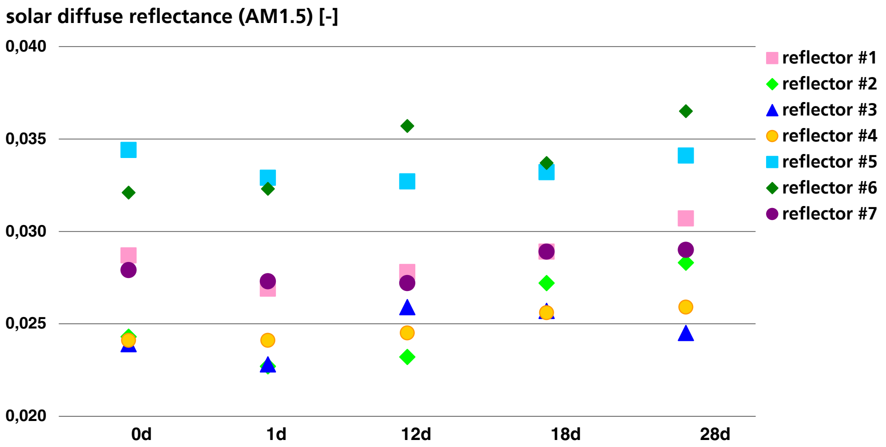


Figure 4: Diffuse solar reflectance for different saline atmosphere cycles for 7 different reflectors.

Over the test period of 28 cycles the optical properties do not change significantly. The values of the direct solar reflectance varies about 2%. Regarding the values of the diffuse solar reflectance, an increase of about 16% after 28 cycles is shown. This can be interpreted as a tendency of a degradation mechanism taking place during the weathering in saline atmospheres.

4.2.2. AFM measurements

The measurements were taken from a reflector coating on aluminum in the initial state and after 18 days cycle in saline atmosphere. The surface area, surface roughness and Peak to Peak values were calculated. The video image of a cleaned reflector after 18 days cycle in saline atmosphere is shown in figure 5. Area 1 indicates a saltspot, area 2 refers to cleaned surface.

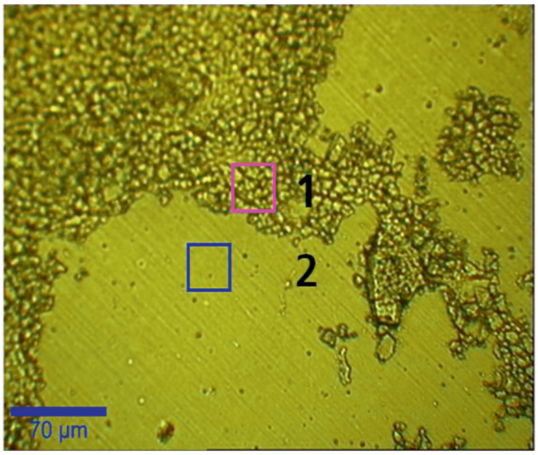


Figure 5: Video image of reflector after 18 days cycle in saline atmosphere. Area 1 indicates a saltspot, area 2 referes to cleaned surface.

Figure 6 shows AFM topography images of the reflector in the initial state. Topography images of the reflector after 18 days cycle in saline atmosphere are shown in figure 7 for an uncleaned (a) and a cleaned surface (b).

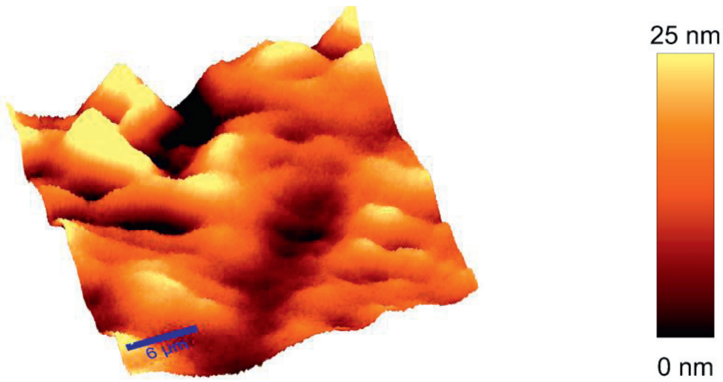
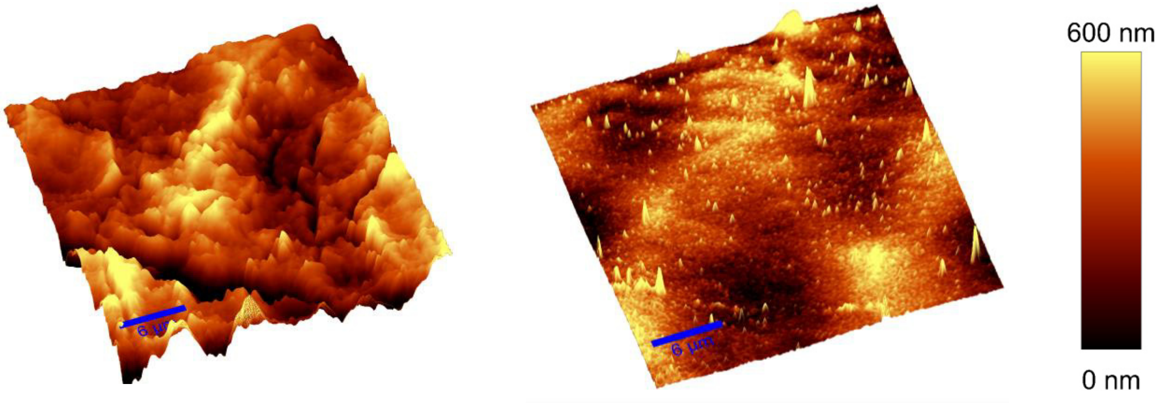


Figure 6: AFM topography micrograph
Reflector on aluminum substrate, initial state



(a) AFM topography micrograph
Reflector on aluminum substrate on salt spot (figure 5 area 1)

(b) AFM topography micrograph
Reflector on aluminum substrate on cleaned spot (figure 5 area 2)

Figure 7: AFM topography of samples of a reflector after 18 days cycle in saline atmosphere (a) and (b).

In Table 2, the true area, surface roughness (SA) and peak-peak value are shown for the initial state and after 18 days cycle in saline atmosphere.

Table 2**:** True area, surface roughness (SA) and peak-peak value initial state and after 18 days cycle in saline atmosphere

Weathering time 3% NaCl @ 40°C [d cycle]	true area [µm²]	SA [nm]	Peak-Peak [nm]
Reference, initial	893,0	4,86	55
18 days cleaned surface	893,8	4,92	170
18 days salt spot	930,5	113,50	1.205

The true area value is not changing significantly for the aged and cleaned samples. However, the surface roughness and the peak-peak value are increased by a factor of about 20 for the weathered and uncleaned surface with respect to the unaged sample. After cleaning the sample, the surface roughness value is decreasing to the initial value. The peak-peak value is reduced to a factor of 3 compared with the initial reference value.

5. Conclusion and outlook

Reflectors, a typical component for solar thermal collectors and systems, have been exposed to outdoor test sites with extreme climatic conditions. Also, accelerated weathering tests under different climatic conditions including a saline atmosphere were performed. The goal is the determination of loads and load levels to analyze the stability and aging behavior of the reflectors.

After a period of 28 days in a defined saline atmosphere cycle, the optical performance of the reflectors is still good. The solar diffuse reflectance shows an increase of about 16%. The microscopic properties are not changing significantly on the aged and cleaned samples. It could be deduced that the investigated reflector samples can stand a heavy saline load, at least for short time. The tests will be continued, especially with a longer testing duration and lower NaCl concentration of the saline atmosphere as they occur in real operation conditions.

Therefore, we will compare the results from the indoor weathering tests with the exposed reflectors from outdoor weathering at the six test sites, especially the samples from the maritime test site at Gran Canaria. This allows the comparison and assessment of expected average soiling rates for individual regions.

A quality check concerning the impact of saline atmospheres is indispensable because in maritime countries, where this type of atmosphere is predominant, solar thermal collectors are frequently used for the preparation of domestic hot water and solar cooling and these are the most populated regions worldwide.

Acknowledgements

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